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Indian Standard

FLOW MEASUREMENT OF NATURAL GAS BY ULTRASONIC METER

ICS 75.160.30; 75.180.30

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Weights and Measures Sectional Committee, PG 26

FOREWORD

This Indian Standard was adopted by the Bureau of Indian Standards, after the draft finalized by the Weights and Measures Sectional Committee had been approved by the Production and General Engineering Division Council.

This standard is taken for measuring the gas consumption at the bulk suppliers as well as at the users' end, when the gas is supplied through the pipelines. In order to meet the requirement of bulk supplier and large consumer, Bureau of Indian Standards has formulated standard for accuracy of metering system and regulation of gas at different delivery point to fulfil the consumer satisfaction as well as financial help of the organization. This standard is basically a performance-based specification of Multipath Ultrasonic Meters and should meet or exceed the accuracy, functional and testing requirements. The users should follow the applicable installation recommendations as indicated in this standard.

In preparing this standard considerable of assistance has been taken from the following publications:

ISO/CD 17089 Measurement of fluid flow in closed conduits — Ultrasonic meters for gas

ISO/TR 12765 : 1997(E) Measurement of fluid flow in closed conduits — Methods using transit time ultrasonic flow-meters

AGA 8 American gas authority report for compressibility and super compressibility

AGA 9 American gas authority report for ultrasonic meters

AGA 10 American gas authority report for speed of sound in natural gas and other related hydrocarbon gases

OIML R6 General provisions of gas volume meters

OIML D11 General requirements for electronic measuring instruments

Indian Standard

FLOW MEASUREMENT OF NATURAL GAS BY ULTRASONIC METER

1 SCOPE

This standard covers multipath ultrasonic transit-time flow-meters, used for custody transfer measurement of natural gas for gas temperature between –10° to 55°C. Multipath ultrasonic meters shall have at least two independent pairs of measuring transducers (acoustic paths).

2 PRINCIPLE OF MEASUREMENT

Multipath ultrasonic meters are inferential meters that derive the gas flowrate by measuring the transit times of high-frequency sound pulses. Transit times are measured for sound pulses travelling diagonally across the pipe, downstream with the gas flow and upstream against the gas flow. The difference in these transit times is related to the average gas flow velocity along the acoustic paths. Numerical calculation techniques are then used to compute the average axial gas flow velocity and the gas volume flowrate at line conditions through the meter.

The accuracy of an ultrasonic gas meter depends on several factors, such as,

a) precise geometry of the meter body and ultrasonic transducer locations;
b) integration technique inherent in the design of the meter;
c) quality of the flow profile, levels of pulsation that exist in the flowing gas stream and gas uniformity; and
d) accuracy of the transit-time measurements.

The accuracy of the transit-time measurements depends on the electronic clock stability,

a) consistent detection of sound pulse wave reference positions; and
b) proper compensation for signal delays of electronic components and transducers.

3 TERMINOLOGY

For the purpose of this standard, the following definitions shall apply:

3.1 Auditor — Representative of the operator or other interested party that audits operation of multipath ultrasonic meter.

3.2 Designer — Company that designs and constructs metering facilities and purchases multipath ultrasonic meters.

3.3 Inspector — Representative of the designer who visits the manufacturer's facilities for quality assurance purposes.

3.4 Manufacturer — Company that designs, manufactures, sells and delivers multipath ultrasonic meters. Company that operates multipath ultrasonic meters and performs normal maintenance.

3.5 Flowrate — Volume per unit of time at metering conditions.

3.6 Indication — The flowrate indicated by the meter.

3.7 Working Range — Range of flowrates of gas limited by the maximum flowrate q_{Max} and the minimum flowrate q_{Min}, for which the meter error lies within specified limits, sometimes also called rangeability.

3.8 Metering Pressure — Absolute gas pressure in a meter at flowing conditions to which the indicated volume of gas is related.

3.9 Average Velocity — Flowrate per unit of cross-sectional area.

3.10 Meter Body — Pressure-containing structure of the meter.

3.11 Acoustic Path — Path travelled by an acoustic wave between a pair of ultrasonic transducers.

3.12 Deviation — The difference between the actual volume flowrate (for example, flowrates in engineering units) measured by the meter under test and the actual volume flowrate measured by a reference meter. Corrections shall be made for the differences in flowing gas pressure, temperature and compressibility between the two meters. The deviation is also measured as a difference between the mass flowrate through the meter under test and the mass flowrate through the reference meter. Typically, three or more test runs are averaged to establish the deviation at each nominal flowrate. These test runs can be used to determine the repeatability as defined below.

3.13 Error — The observed deviation of a meter calculated as: Percent error shall be divided by [(Test meter reading — Reference meter reading)/Reference meter reading] × 100.

3.14 Maximum Error — The allowable error limit within the specified operational range of the meter.

3.15 Maximum Peak-to-Peak Error — The largest allowable difference between the upper-most error point and the lower-most error point.

3.16 q_{Max} — The maximum gas flowrate through the USM that can be measured within the error limits.

3.17 q_t — The transition gas flowrate below which the expanded error limit is applicable, and where $q_t \leq : 0.1\, q_{Max}$.

3.18 q_{Min} — The minimum gas flowrate through the USM that can be measured within the expanded error limits.

3.19 q_i — The actual measured gas flowrate passing through a USM under a specific set of test conditions.

3.20 Reference Meter — A meter or measurement device of proven flow measurement accuracy.

3.21 Repeatability — The closeness of agreement among a number of consecutive measurements of the output of the test meter for the same reference flowrate under the same operating conditions, approaching from the same direction, for full scale traverses. The repeatability shall correspond to the 95 percent confidence interval of the deviation based on the assumption of a normal distribution.

3.22 Resolution — The smallest step by which the change of the flow velocity is indicated by the meter.

3.23 SPU — Signal processing unit.

3.24 USM — Ultrasonic meter.

3.25 Velocity Sampling Interval — The time interval between two succeeding gas velocity measurements by the full set of transducers or acoustic paths. Typically, between 0.05 and 0.5 s, depending on meter size.

3.26 Zero-Flow Reading — The maximum allowable flow-velocity reading when the gas is at rest; that is, both the axial and the non-axial velocity components are essentially zero.

4 OPERATING CONDITIONS

4.1 Gas Quality

4.1.1 The meter shall, as a minimum requirement, operate with any of the normal range natural gas composition mixtures. This includes relative densities of pure methane between 0.55 and 0.87.

The manufacturer shall be consulted if any of the following are expected: (a) acoustic wave attenuation carbon dioxide levels are above 10 percent, (b) operation near the critical density of the natural gas mixture, (c) the total sulphur level exceeds 320 ppm approximately including mercaptans hydrogen sulphide and elemental sulphur compounds.

Deposits due to normal gas pipeline conditions (for example, condensates or traces of oil mixed with mill-seal, dirt or sand) may affect the meter's accuracy by reducing the meter's cross-sectional area. Deposits shall also attenuate or obstruct the ultrasonic sound waves emitted from and received by the ultrasonic transducers, and in some designs reflected by the internal wall of the meter.

4.2 Pressures

Ultrasonic transducers used in USM require a minimum gas density (a function of pressure) to ensure acoustic coupling of the sound pulses to and from the gas. Therefore, the designer shall specify the expected minimum operating pressure as well as the maximum operating pressure.

4.3 Temperatures, Gas and Ambient

The USM should operate over a flowing gas temperature range of –10° to 55°C. The manufacturer shall specify the expected operating gas temperature range.

The operating ambient air temperature range shall be –10° to 55°C. This ambient temperature range applies to the meter body with and without gas flow, field-mounted electronics, ultrasonic transducers, cabling, etc.

The manufacturer shall state the flowing gas and ambient air temperature specifications for the multipath ultrasonic meter, if they differ from the above.

4.4 Metering Conditions

Conditions, prevailing at the point of measurement, for example, gas, composition, temperature and pressure.

NOTE — Not preferred alternative: actual conditions.

4.5 Base conditions to which the measured volume of the gas is converted, for example, base temperature and base pressure.

NOTE — Not preferred alternatives: reference-, standard-, normal conditions, etc.

4.6 Gas Flow Considerations

The flowrate limits that may be measured by a USM are determined by the actual velocity of the flowing gas. The designer should determine the expected gas flowrates and verify that these values are within the q_{Min}, q_t and q_{Max} specified by the manufacturer. The accuracy requirement for operation within q_{Min}, q_t and q_{Max}. The designer should examine carefully the maximum velocity for noise and piping safety (erosion, thermowave vibrations, etc) concerns.

USM have the inherent capability of measuring flow in either direction with equal accuracy; that is, they are bi-directional. The designer should specify if bi-directional measurement is required so that the manufacturer may properly configure the SPU parameters.

4.7 Upstream Piping and Flow-Profiles

Upstream piping configurations may adversely affect the gas velocity profile entering a USM to such an extent that measurement error occurs. The magnitude of the error, if any, should be a function of the meter's ability to correctly compensate for such conditions.

5 METER REQUIREMENTS

5.0 The meter body and all other parts, including the pressure-containing structures and external electronic components, shall be designed and constructed of materials suitable for the service conditions for which the meter is rated, and in accordance with any codes and regulations applicable to each specific meter installation, as specified by the designer.

5.1 Meter Body

5.1.1 *Maximum Operating Pressure*

Meters shall be manufactured to meet one of the common pipeline flange classes — ANSI Class 300, 600, 900, etc. The maximum design operating pressure of the meter shall be the lowest of the maximum design operating pressure of the following: meter body, flanges, transducer connections, transducer assemblies.

The required maximum operating pressure shall be determined using the applicable codes for the jurisdiction in which the meter will be operated and for the specified environmental temperature range. The designer should provide the manufacturer with information on all applicable codes for the installation site and any other requirements specific to the operator.

5.1.2 *Corrosion Resistance*

All wetted parts of the meter shall be manufactured of materials compatible with natural gas and related fluids.

All external parts of the meter shall be made of a non-corrosive material or sealed with a corrosion-resistant coating suitable for use in atmospheres typically found in the natural gas industry, and/or as specified by the designer.

5.1.3 *Meter Body Lengths and Bores*

The manufacturers should publish their standard overall face-to-face length of the meter body with flanges, for each ANSI flange class and diameter. The designer, as an option, may specify a different length to match existing piping requirements.

The USM bore and the adjacent upstream pipe along with flanges should have the same inside diameter to within 1 percent of each other. For bi-directional applications, both ends of the meter shall be considered upstream.

5.1.4 *Ultrasonic Transducer Ports*

As natural gas may contain some impurities (for example, light oils or condensates), transducer ports shall be designed in a way that reduces the possibility of liquids or solids accumulating in the transducer ports.

If specified by the designer and available from the manufacturer, the meter shall be equipped with valves and necessary additional devices, mounted on the transducer ports in order to make it possible to replace the ultrasonic transducers without depressurizing the meter run. In that case, a bleed valve may be required in addition to the isolation valve to ensure that no pressure exists behind a transducer before releasing the extraction mechanism.

5.1.5 *Pressure Tap*

At least one pressure tap shall be provided for measuring the static pressure in the meter. Each pressure tap hole shall be between 3 mm and 10 mm nominal in diameter and cylindrical over a length at least 2.5 times the diameter of the tapping measured from the inner wall of the meter body. The tap hole edges at the internal wall of the meter body shall be free of burrs and wire edges, and have minimum rounding.

For a meter body with a wall thickness less than 8 mm, the hole shall be 3 mm nominal in diameter.

Female pipe threads shall be provided at each pressure tap preferably for a 6 mm or 12 mm thread for isolation valve. Turning radius clearance shall be provided to allow a valve body to be screwed directly into the pressure tap. Pressure taps can be located at the top, left side, and/or right side of the meter body. Additional taps may provide the designer with flexibility in locating pressure transducers for maintenance access and proper drainage of gauge line condensates back into the meter body.

5.1.6 *Miscellaneous*

The meter shall be designed in such a way that the body will not roll when resting on a smooth surface with a slope of up to 10 percent. This is to prevent damage to the protruding transducers and SPU when the USM is temporarily set on the ground during installation or maintenance work.

The meter shall be designed to permit easy and safe handling of the meter during transportation and installation. Hoisting eyes or clearance for lifting straps shall be provided.

6 ULTRASONIC TRANSDUCERS

6.1 General

The manufacturers shall state the general specifications of their ultrasonic transducers, such as critical dimensions, maximum allowable operating pressure, operating pressure range, operating temperature range and gas composition limitations.

The manufacturer shall specify the minimum operating pressure based on the ultrasonic transducer model, USM size and expected operating conditions. This minimum pressure shall be marked or tagged on the USM to alert the operator's field personnel that the meter may not register flow at reduced pipeline pressures.

6.2 Rate of Pressure Change

Sudden depressurization of an ultrasonic transducer may cause damage if a trapped volume of gas expands inside the transducer. If necessary, clear instructions shall be provided by the manufacturer for depressurization and pressurization of the meter and transducers during installation, start-up, maintenance and operation.

It shall be possible to replace or relocate transducers without a significant change in meter performance. This means that after an exchange of transducers and a possible change of SPU software constants directed by the manufacturer, the resulting shift in the meter's performance shall not be outside the limits of the performance.

The manufacturer shall specify procedures to be used when transducers have to be exchanged, and possible mechanical, electrical or other measurements and adjustments have to be made.

6.3 Transducer Tests

Each transducer or pair of transducers shall be tested by the manufacturer and the results documented as part of the USM quality assurance programme. Each transducer shall be marked or tagged with a permanent serial number and be provided with the general transducer. If the SPU requires specific transducer characterization parameters, each transducer or transducer pair shall also be provided with test documentation that contains the specific calibration test data, calibration method used and characterization parameter(s).

7 ELECTRONICS

7.1 General Requirements

The USM electronics system, including power supplies, micro computer, signal processing components and ultrasonic transducer excitation circuits, may be housed in one or more enclosures mounted as per the agreement between the supplier and the users.

Optionally, a remote unit containing the power supplies and the operator interface may be installed in a non-hazardous area and connected to the SPU by multi-conductor cable.

The SPU shall operate over its entire specified environmental conditions within the meter performance requirements. It shall also be possible to replace the entire SPU or change any field replacement module without a significant change in meter performance 'Significant change'.

The system shall contain a watch-dog-timer function to ensure automatic restart of the SPU in the event of a program fault or lock-up.

The meter shall operate from a power supply of nominal 120V a.c. or 240V a.c. at 50 Hz or from nominal 12V d.c. or 24V d.c. power supply/battery systems, as per the agreement between the supplier and the user.

7.2 Output Signal Specifications

The SPU shall be equipped with at least one of the following outputs:

a) serial data interface; and
b) frequency, representing flowrate at line conditions.

The meter may also be equipped with an analog (4-20mA, d.c.) output for flowrate at line conditions. Flowrate signal shall be scaleable up to 120 percent of the meter's maximum flowrate, q_{Max}.

A low-flow cut-off function shall be provided that sets the flowrate output to zero when the indicate flowrate is below a minimum value (not applicable to serial data output).

Two separate flowrate outputs and a directional state output or serial data values shall be provided for bi-directional applications to facilitate the separate accumulation of volumes by the associated flow computer(s) and directional state output signal.

All outputs shall be isolated from ground and have the necessary voltage protection to meet the electronics design testing requirements.

7.3 Electrical Safety Design Requirements

The design of the USM, including the SPU, shall be analyzed, tested and certified by an applicable laboratory, and then each meter shall be labelled as approved for operation in a National Electric Code and Hazardous Area, at a minimum. Intrinsically safe designs and explosion proof enclosure designs are generally certified and labelled. The manufacturer shall specify the more location requirement to achieve a more conservative installation design.

Cable jackets, rubber, plastic and other exposed parts shall be resistant to ultraviolet light, flames, and grease.

8 COMPUTER PROGRAMMES

8.1 Firmware

Computer codes responsible for the control and operation of the meter shall be stored in a non-volatile memory. All flow-calculation constants and the operator-entered parameters shall also be stored in non-volatile memory.

For auditing purposes, it shall be possible to verify all flow-calculation constants and parameters which the meter is in operation.

The manufacturer should maintain a record of all firmware revisions, including revision serial number date of revision, applicable meter models, circuit board revisions and a description of changes to the firmware.

The firmware revision number, revision date, serial number and/or checksum shall be available to the auditor by visual inspection of the firmware chip, display or digital communications port.

The manufacturer may offer firmware upgrades from time to time to improve the performance of the meter or add additional features. The manufacturer shall notify the operator if the firmware revision will affect the accuracy of a flow-calibrated meter.

The meter shall be supplied with a capability for local or remote configuring of the SPU and for monitoring the operation of the meter. As a minimum, the software shall be able to display and record the following measurements: flowrate at line conditions, mean velocity, average speed of sound, speed of sound along each acoustic path and ultrasonic acoustic signal quality received by each transducer. As an option, the manufacturer may provide these software functions as part of the meter's embedded software.

8.2 Inspection and Auditing Functions

8.2.1 It shall be possible for the auditor or the inspector to view and print the flow measurement configuration parameters used by the SPU; for example, calibration constants, meter dimensions, time averaging period and sampling rate.

Provisions shall be made to prevent an accidental or undetectable alteration of those parameters that affects the performance of the meter. Suitable provisions include a sealable switch or jumper, a permanent programmable read-only memory chip or a password in the SPU.

8.2.2 *Optional Requirement*

It shall be possible for the auditor to verify that all algorithms, constants and configuration parameters being used, in any specific meter, are producing the same or better performance as when the meter design was originally flow-tested or when the specific meter was last flow-calibrated and any calibration factors were changed. The auditor may have to rely on the manufacturer for portions of this verification because of the proprietary nature of some USM algorithms.

8.3 Alarms

The following alarm-status outputs shall be provided in the form of fail-safe, dry, relay contacts or voltage-free solid-state switches isolated from ground:

a) *Output Invalid*: when the indicated flowrate at line conditions is invalid;

b) *Trouble (Optional)*: when any of several monitored parameters fall outside of normal operation for a significant period of time; and

c) *Partial Failure (Optional)*: when one or more of the multiple ultrasonic path results is not usable.

8.4 Diagnostic Measurements

The manufacturer shall provide the following and other diagnostic measurements *via* a serial data interface.

a) Average axial flow velocity through the meter;

b) Flow velocity for each acoustic path (or equivalent for evaluation of the flowing velocity profile);

c) Speed of sound along each acoustic path;

d) Average speed of sound;

e) Velocity sampling interval;

f) Averaging time interval;

g) Percentage of accepted pulses for each acoustic path;

h) Status and measurement quality indicators; and

j) Alarm and failure indicators.

8.5 Units

The following units shall be used for the various values associated with the USM:

Parameter	*Units*
Density	kg/m^3
Energy	J
Mass	kg
Pipe diameter	mm
Pressure	Pa or MPa
Temperature	°C
Velocity	m/s
Viscosity, absolute dynamic	cP or Pa·s
Volume	m^3
Actual volume flow rate (at flowing conditions)	m^3/h

8.6 Password Security

The flow-computer shall have a password security protection system for configuration of various parameters in the flow computer.

8.7 Documentation

This standard requires documentation on accuracy, installation effects, electronics, ultrasonic transducers and zero-flow verification. The manufacturer shall also provide all necessary data, certificates and documentation for a correct configuration, set-up and use of the particular meter so that it operates correctly. This includes an operator's manual, pressure test certificates, material certificates, measurement report on all geometrical parameters of the spool piece and certificates specifying the zero-flow verification parameters used.

The manufacturer shall provide the following set of documents, at a minimum. All documentation shall be dated.

a) Description of the meter, giving the technical characteristics and the principle of its operation;
b) Perspective drawing of the meter;
c) Nomenclature of parts with a description of constituent materials of such parts;
d) Assembly drawing with identification of the component parts listed in the nomenclature;
e) Dimensioned drawing;
f) Drawing showing the location of verification marks and seals;
g) Dimensioned drawing of metrologically important components;
h) Drawing of the data plate or face plate and of the arrangements for inscriptions;
j) Drawing of any auxiliary devices;
k) Instructions for installation, operation, periodic maintenance and trouble-shooting;
m) Maintenance documentation, including third-party drawings for any field-repairable components;
n) Description of the electronic SPU and its arrangement, and a general description of its operation;
p) Description of the available output signals and any adjustment mechanisms;
q) List of electronic interfaces and user wiring termination points with their essential characteristics;
r) Description of software functions and SPU configuration parameters, including their default value and operating instructions;
s) Documentation that the design and construction comply with applicable safety codes and regulations;
t) Documentation that the meter's performance meets the requirements;
u) Documentation that the meter's design successfully passed the tests in 'Electronics Design Testing';
v) Upstream and downstream piping configurations in minimum length that will not create an additional flowrate measurement error of more than ±0.3 percent;
w) Maximum allowable flow-profile disturbance, which will not create an additional rate measurement error of more than ±0.3 percent;
y) Field verification test; and
z) List of the documents submitted.

8.8 After Receipt of Order

The manufacturer shall furnish specific meter outline drawings, including overall flange face-to-face dimensions, inside diameter, maintenance space clearances, conduit connection points and estimated weight.

The manufacturer should provide a recommended list of spare parts. The manufacturer should also furnish meter-specific electrical drawings that show customer wiring termination points and associated electrical schematics for all circuit components back to the first isolating component; for example, optical isolator, relay, operational amplifier, etc. This should allow the designer to properly design the interfacing electronic circuits.

8.9 Before Shipment

Prior to shipment of the meter, the manufacturer shall make the following available for the inspector's review: metallurgy reports, weld inspection reports, pressure test reports and final dimensional measurements.

9 NOISE ISSUE IN ULTRASONIC METER

The speed of sound measured by a USM, the measured SOS (MSOS), is influenced by:

a) Gas composition,
b) Pressure,
c) Temperature,
d) Changes in the geometry of the measurement section, and
e) Changes in transit time measurement (by the meter).

The speed of sound may be calculated from measured values of pressure, temperature and gas composition using AGA 10 — 'theoretical SOS' (TSOS).

9.1 Absolute SOS Comparison

If both MSOS and TSOS are available they shall be compared by the absolute comparison. Differences between MSOS and TSOS as follows.

9.1.1 A synchronous determination of MSOS and TSOS due to fluctuations in gas composition and analysis time lag.

9.1.2 Malfunction of:

a) USM,
b) Pressure measurement,
c) Temperature measurement, and
d) Gas composition measurement.

9.1.3 Depositions on the transducer(s) and/or meter body which changes the path length. Statistical techniques should be used for monitoring MSOS and TSOS over time.

10 PERFORMANCE REQUIREMENTS

10.0 General

The general flow-measurement performance of all USM shall meet the following requirements, prior to making any calibration-factor adjustment (*see* Fig. 1):

Repeatability	:	±0.2 percent for $q_t \leq q_i \leq q_{Max}$ ±0.4 percent for $q_{Min} \leq q_i < q_t$
Resolution	:	0.001 m/s
Velocity sampling interval	:	≤ 1 s
Maximum peak-to-peak error	:	0.7 percent for $q_t \leq q_i \leq q_{Max}$
Zero-flow reading	:	< 12 mm/s for each acoustic path

10.1 The ultrasonic meter shall be flow-calibrated. If a meter is flow-calibrated, then it shall meet the same minimum measurement performance requirements before the application of any calibration-factor adjustment. The amount of calibration-factor adjustment, therefore, shall be within the error limits stated in the performance requirements. This is to ensure that a major flaw in the meter is not marked by a large calibration-factor adjustment. Calibration-factor adjustments are made to minimize a meter's measurement bias error. The manufacturer shall explain the methods and benefits of flow-calibrating meter and calibration-factor adjustment. The design shall also follow carefully the installation recommendations. Any installation effect shall add to the overall measurement uncertainty.

10.2 If a meter is not flow-calibrated, the manufacturer shall provide sufficient test data confirming that each meter shall meet these performance requirements.

10.3 For each meter design and size, the manufacturer shall specify flowrate limits for $q_{Min,}$ q_t and q_{Max}. Whether flow-calibrated or not, it shall perform within the more accurate measurement range for gas flowrates from q_t to q_{Max} and within the less accurate range for gas flowrate less than q_l but greater than or equal to q_{Max}.

10.4 Large Meter Accuracy

USM of 300 mm (nominal) diameter size and larger shall meet the following flow-measurement accuracy requirements, prior to making any calibration-factor adjustment.

Maximum error: ±0.7 percent for $q_t \leq q_{Min} : \leq q_{Max}$ (*see* Fig. 1) ±1.4 percent for $q_{Min} : \leq q_j < q_t$.

10.5 Small Meter Accuracy

USM less than 300 mm (nominal) diameter shall meet the following flow-measurement accuracy requirements, prior to making any calibration-factor adjustment. Note that the requirements for the smaller meters have been relaxed slightly because of the difficulty in measuring acoustic transit times in turbulent gas flow when the path lengths are shorter (*see* Fig. 1).

Maximum Error : ± 1.0 percent for $q_t = q_i = q_{Max}$
: ± 1.4 percent for $q_{Min} \leq q_i < q_t$

10.6 Pressure, Temperature and Gas Composition Influences

The USM shall meet the flow measurement accuracy requirements over the full operating pressure, temperature and gas composition ranges without the need for manual adjustment, unless otherwise stated

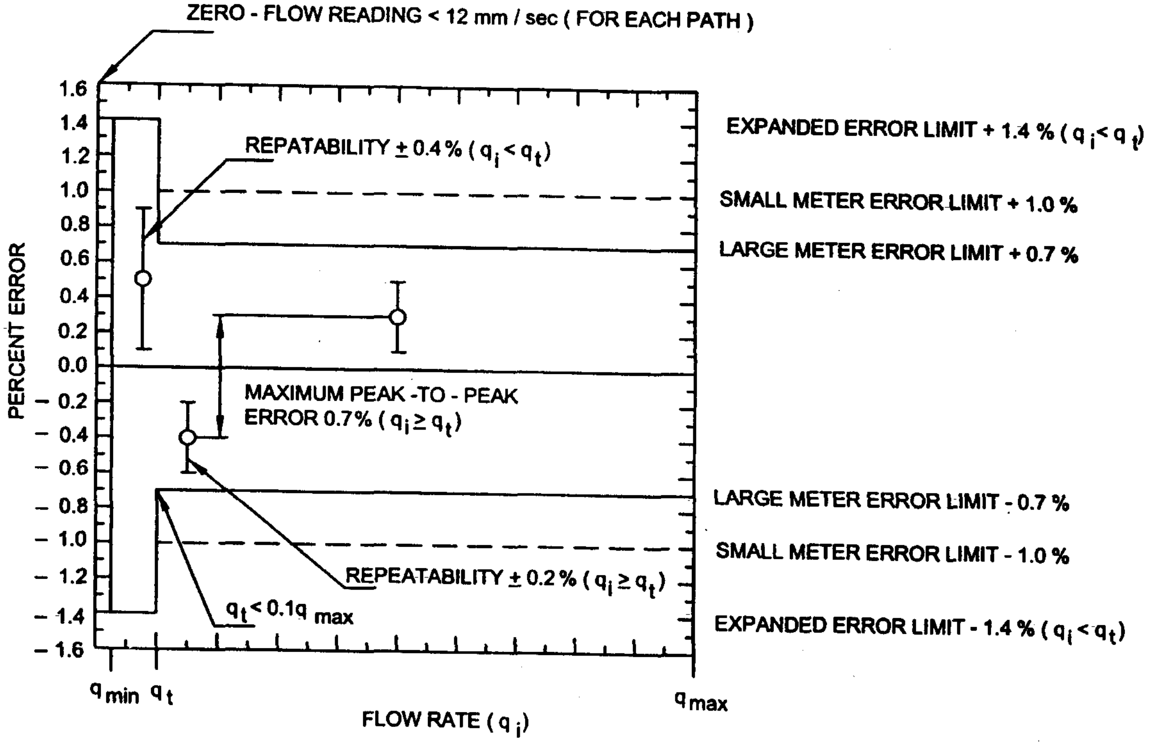

FIG. 1 PERFORMANCE SPECIFICATION SUMMARY

by the manufacturer. If the USM requires a manual input to characterize the flowing gas conditions (for example, gas density and viscosity), the manufacturer shall state the sensitivity of these parameters so that the operator can determine the need to change these parameters as operating conditions change.

11 INDIVIDUAL METER TESTING REQUIREMENTS

Prior to the shipment of each USM to the designer or the operator, the manufacturer shall perform the following tests and checks on each meter. The results of all tests and checks performed on each meter shall be documented in a report prepared by the manufacturer and submitted to the designer or the operator.

11.1 Leakage Tests

Every USM, complete with transducers and transducer isolation valves (if used), shall be leak-tested by the manufacturer after final assembly and prior to shipment to the designer or flow-calibration facility. The test medium shall be an inert gas, such as nitrogen. The leak test pressure shall be a minimum of 1 380 kPa maintained for a minimum of 15 min, with no leaks detectable with a no corrosive liquid solution or an ultrasonic leak detector. This leak test does not preclude the requirements to perform a hydrostatic qualification test.

11.2 Dimensional Measurements

The manufacturer shall measure and document the average internal diameter of the meter, the length of each acoustic path between transducer faces and the axial (meter body axis) distance between transducer pairs.

The average internal diameter shall be calculated from a total of 12 inside diameter measurements or the equivalent determined by a coordinate measuring machine. Four internal diameter measurements (one in the vertical plane, another in the horizontal plane and two in planes approximately 45° from the vertical plane) shall be made at three meter cross-sections: (a) near the set of upstream ultrasonic transducers, (b) near the set of downstream transducers, and (c) halfway between the two transducer sets.

If the acoustic path lengths or the axial distances between ultrasonic transducer pairs cannot be directly measured, then the unknown distances shall be calculated using right-angle trigonometry and distances that can be measured directly. Where the measurement of angles is difficult and the result is imprecise, such measurements shall not be used to calculate the required distances.

The meter body temperature shall be measured at the time these dimensional measurements are made. The measured lengths shall be corrected to an equivalent length at a meter body temperature of 20°C by applying the applicable coefficient of thermal expansion for the meter body material. The individual corrected lengths shall then be averaged and reported to the nearest 0.01 mm.

All instruments used to perform these measurements shall have valid calibrations traceable to National/International Standards.

These measurements and calculations shall be documented on a certificate, along with the name of the meter manufacturer, meter model, meter serial number, meter body temperature at the time dimensional measurements were made, date, name of the individual who made the measurements and name of the inspector, if present.

11.3 Zero-Flow Verification Test (Zero Tests)

To verify the transit-time measurement system of each meter, the manufacturer shall perform a zero-flow verification test. The manufacturer shall document and follow a detailed test procedure that includes the following elements, at a minimum.

a) After blind flanges are attached to the ends of the meter body, the meter shall be purged of all air and pressurized with a pure test gas or gas mixture. The selection of the test gas shall be the responsibility of the manufacturer. However, the acoustic properties of the test gas must be well known and documented.

b) The gas pressure and temperature shall be allowed to stabilize at the outset of the test. The gas velocities for each acoustic path shall be recorded for at least 30 s. The mean gas velocity and standard deviation for each acoustic path shall then be calculated.

c) Adjustments to the meter shall be made as necessary to bring the meter performance into compliance with the manufacturer's specifications and the specifications stated in this report.

If the measured speed-of-sound values are compared with theoretical values, the theoretically determined value shall be computed using a complete compositional analysis of the test gas, precise measurements of the test gas pressure and temperature and the equation of state used in A.G.A. Report No. 8 — Detailed characterization method.

As part of the test procedure, the manufacturer shall document the ultrasonic transducer serial numbers and their relative locations in the meter body. The manufacturer shall also document all parameters used by the meter; for example, transducer/electronic transit-time delays, incremental timing corrections, and acoustic path lengths, angles, diameters and other parameters used in the calculation of the gas velocity for each acoustic path. The manufacturer should note if the constants are dependent on specific transducer pairs.

The manufacturer may also implement a zero-flow offset factor, in engineering units of positive or negative feet per second or meters per second. This zero-flow offset factor would be applied to the meter's flowrate output. Use of this factor is intended to improve the accuracy of the low gas velocity measurements, while not significantly affecting the accuracy of the higher velocity measurements. This zero-flow offset factor, if used, shall be documented by the manufacturer.

11.4 Flow-Calibration Test

If specified, the USM shall be flow-calibrated at flowrates such as q_{Min}, 0.10 q_{Max}, 0.25 q_{Max}, 0.40 q_{Max}, 0.70 q_{Max}, and q_{Max}.

Flow-calibration tests shall be performed at a gas pressure, temperature and density near the expected average operating conditions as specified by the designer. Tests at any other specific pressure temperature and gas density range may be performed, if necessary. The designer may also require that specific piping configurations and/or flow-conditioners be used during flow-calibration, understanding that differences in upstream piping configurations may influence meter performance.

It is recognized that it may not be possible to test large USM up to their maximum capacity because of the limitations of currently available test facilities. In such cases, the designer may specify a lower flowrate instead of q_{Max}. The manufacturer should state on an applicable documents if a reduced q_{Max} was used during flow-calibration tests.

The upstream flange and piping internal diameters shall match and be aligned with the meter under test 'Protrusions'.

A test measurements performed by a flow-calibration facility shall be tràceable with current calibration certificates to the applicable National/International Standards. Thermo physical values (for example, density, compressibility, speed of sound, critical flow factor, etc) used during flow-calibration shall be specified.

11.4.1 *Calibration-Factors Adjustment*

If a meter is flow-calibrated, the calibration-factors should normally be applied to eliminate any indicated meter bias error. Some suggested methods of applying calibration-factors are:

a) Using flow-weighted mean error (FWME) over the meter's expected flow range; and

b) Using a more sophisticated error correction schedule (for example, a multi-point or polynomial algorithm, a piecewise linear interpolation method, etc) over the meter's range of flowrates.

For bi-directional flow-calibrations, a second set of calibration factors may be used for reverse flow.

If an offset factor was established during the zero-flow validation tests, it may be revised based on the results of the flow-calibration to optimize the meter's overall accuracy performance. The manufacturer shall document such a change in this factor and alert the operator that the zero-flow output may have some intentional bias in order to improve accuracy at q_{Min}.

11.4.2 *Test Reports*

The results of each test required, shall be documented in a written report supplied to the designer or the operator by the manufacturer. For each meter, the report shall include, at a minimum:

a) Name and address of the manufacturer;
b) Name and address of the test facility;
c) Model and serial number;
d) SPU firmware revision number;
e) Date(s) of the test;
f) Name and title of the person(s) who conducted the tests;
g) Written description of the test procedures;
h) Upstream and downstream piping configurations;
j) Diagnostic report of the software configuration parameters;
k) All test data, including flowrates, pressures, temperatures, gas composition and the measurement uncertainty of the test facility; and
m) Description of any variations or deviations from the required test conditions.

At least one copy of the complete report shall be sent to the designer or the operator and one copy retained in the manufacturer's files. The manufacturer shall ensure that the complete report is available to the operator on request, for a period of 10 years after shipment of any meter.

11.5 Quality Assurance

The manufacturer shall establish and follow a written comprehensive quality assurance programme for the assembly and testing of the meter and its electronic system. This quality assurance programme shall be available to the inspector.

12 INSTALLATION REQUIREMENTS

This section is directed to the designer to ensure that the USM will be installed in a suitable environment and in a piping configuration that allows the USM to meet the expected performance requirements.

12.1 Environmental Considerations

12.1.1 *Temperature*

The manufacturer shall provide ambient temperature specifications for the USM. Consideration; shall be given to providing shade, heating and/or cooling to reduce the ambient temperature extremes.

12.1.2 *Vibration*

USM should not be installed where vibration levels or frequencies might excite the natural frequencies of SPU boards, components or ultrasonic transducers. The manufacturer shall provide specification regarding the natural frequencies of the OM components.

12.1.3 *Electrical Noise*

The designer and the operator shall not expose the USM or its connected wiring to any unnecessary electrical noise, including alternating current, solenoid transients or radio transmissions. The manufacturer shall provide instrument specifications regarding electrical noise influences.

12.2 Piping Configuration

12.2.1 *Flow Direction*

For bi-directional applications, both ends of the meter shall be considered upstream.

12.2.2 *Piping Installations*

Various combinations of upstream fittings, valves and lengths of straight pipe can produce velocity profile distortions at the meter inlet that may result in flowrate measurement errors. The amount meter error will depend on the type and severity of the flow distortion produced by the upstream piping configuration and the meter's ability to compensate for this distortion. Research work on installation effects is ongoing, so the designer should consult with the manufacturer to review the latest test results and evaluate how the accuracy of a specific USM design may be affected by the upstream piping configuration of the planned installation. In order to achieve the desired meter performance, it may be necessary for the designer to alter the original piping configuration or include a flow-conditioner as part of the meter run.

To ensure that the USM, when installed in the operator's piping system, shall perform within the specified flowrate measurement accuracy limits. The manufacturer shall follow the desired requirement of the operator:

a) Recommend upstream and downstream piping configuration in minimum length- one without a flow-conditioner and one with a flow-conditioner — that will not create an additional flowrate measurement error of more than ±0.3 percent due to the installation configuration. This error limit should apply for any gas flowrate between q_{Min} and q_{Max}. The recommendation shall be supported by test data.

b) Specify the maximum allowable flow-disturbance (for example, the limits on swirl angle, velocity profile asymmetry, turbulence intensity, etc) at the meter's upstream flange or at some specified axial distance upstream of the meter that will not create an additional flowrate measurement error of more than ±0.3 percent due to the installation configuration. This error limit should apply for any gas flowrate between q_{Min} and q_{Max}. The recommendation shall be supported by test data.

Instead of following the manufacturer's recommendation in (a) or (b) above, the designer may choose to flow-calibrate the USM or in a flow-calibration facility where the test piping configuration can be made identical to the planned installation.

Research has indicated that a symmetric velocity profiles may persist for 50 pipe diameters or more downstream: from the point of initiation. Swirling velocity profiles may persist for 200 pipe diameters or more. A flow-conditioner properly installed upstream of a USM may help shorten the length of straight pipe required to eliminate the effects of an upstream flow-disturbance. A USM may be able to compensate for some level of flow-profile disturbance. Research is still being conducted to quantify the sensitivity of different USM designs to various flow-profile disturbances.

12.2.3 *Protrusions*

Changes in internal diameters and protrusions shall be avoided at the USM inlet because they create local disturbances to the velocity profiles. The USM bore, flanges and adjacent upstream pipe should all have the same inside diameter, to within 1 percent, and be aligned carefully to minimize flow-disturbances, especially at the upstream flange. The upstream flange's internal weld shall be ground smooth. No part of the upstream gasket or flange face edge should protrude into the flow-stream by more than 1 percent of the internal diameter. During installation, three or more insulating flange bolt sleeves can be used at the 4, 8 and 12 o'clock positions to keep the gasket centered while tightening the nuts.

Thermowells, located are excluded from the above protrusion limits.

12.2.4 *Internal Surface*

The internal surface of the USM shall be kept clean of any deposits due to condensates or traces of oil mixed with mill-scale, dirt or sand, which may affect the meter's cross-sectional area. The USM operation depends on a known cross-sectional area to convert mean gas velocity to a flowrate. If a layer of deposits accumulates inside the USM, the cross-sectional area will be reduced, causing a corresponding increase in gas velocity and a positive measurement error.

Examples: Given a 150 mm internal diameter USM, a deposit layer of only 0.02 mm around the inside surface will cause a +0.53 percent flow-measurement error. For a 500 meter, the same 0.02 mm coating would cause a +0.16 percent error.

12.2.5 *Thermowells*

For uni-directional flow, the designer should have the thermowell installed downstream of the meter. The distance from the downstream flange face to the thermowell shall be between $2D$ and $5D$. For bi-directional flow installations, the thermowell shall be located at least $3D$ from either USM flange face where D is defined as the nominal diameter of the meter.

Research on the effects of thermowell placement is ongoing and the designer should consult with the manufacturer for recommendations based on the most current test data. The thermowell orientation with respect to acoustic paths should also be recommended by the manufacturer.

The designer is cautioned that high gas velocities may cause flow-induced thermowell vibration. Catastrophic metal fatigue failure of the thermowell could eventually result from the vibration.

12.2.6 *Accoustic Noise Interference*

Some pressure-reducing control valves, designed to reduce audible noise, shall produce very high levels of ultrasonic noise under certain flowing conditions. The ultrasonic noise from these quiet control valves can interfere with the operation of a nearby ultrasonic meter. Research work on ultrasonic noise interference is ongoing, so the manufacturer shall be consulted when planning to install a USM near a pressure-reducing control valve.

12.2.7 *Flow-Conditioners*

Flow-conditioners may or may not be necessary, depending on the manufacturer's meter design and the severity of any upstream flow-profile disturbance. The designer should consult with the manufacturer to determine the benefits, if any, of installing various types of flow-conditioners, given the upstream piping configuration.

12.2.8 *Orientation of Meter*

The designer should go by with the manufacturer recommendation to determine if there is a preferred meter Orientation for a given upstream piping configuration that is known to produce flow-profile distortions.

12.2.9 *Filtration*

Filtration of the flowing gas is probably not necessary for most applications of a USM. However, the accumulation of deposits due to a mixture of dirt, mill scale, condensates and/or lubricating oils shall be avoided. Filtration may be necessary if any of the above conditions is known to exist.

12.3 Associated Flow-Computer

The USM output is typically an uncorrected volume (actual volume at line conditions), either per unit of time or accumulated. Therefore, an associated flow-computer or corrector must be installed by the designer to correct the volume rate and accumulated volume for pressure, temperature and compressibility (to obtain standard cubic feet, for example), and to provide the necessary data retention and audit trail.

For bi-directional applications, the USM shall be treated as two separate meters, associated with two 'meter runs' in a single flow-computer or with two separate flow-computers.

12.3.1 *Flow-Computer Calculations*

The necessary calculations are summarized in the following expressions:

$$Q_b = Q_f (P_f/P_b)\,(T_b/T_f)\,(Z_b/Z_f)$$

$$V_b = \text{integration } Q_b d_t$$

where

Q_b = flowrate at base conditions b;
Q_f = flowrate at flowing conditions;
P_b = base pressure, 101.325 kPa;
P_f = absolute static pressure of gas at flowing conditions;
T_b = base temperature, 288.15K;
T_f = absolute temperature of gas at flowing conditions;
Z_b = compressibility factor of gas at base conditions;
Z_f = compressibility factor of gas at flowing conditions;
V_b = accumulated volume at base conditions (Integration symbol = integrated over time); and
d_t = integration increments of time, typically 1 s.

The first equation converts the flowrate at line conditions of pressure, temperature and compressibility to a flowrate at base conditions. The second equation represents the accumulation process in which flowrates at base conditions are accumulated to volumes over time.

12.4 Maintenance

The operator should follow the manufacturer's recommendations for maintenance. Periodic maintenance could be as simple as monitoring several SPU diagnostic measurements, such as signal quality and speed of sound for each acoustic path. For example, it may be possible to detect an accumulation of deposits on the transducer faces by measuring a reduction in the received ultrasonic pulse strength.

When possible, the operator should verify that the USM measures near zero when no gas is flowing through the meter. When performing this test, the operator should bypass or defeat any low flow cut-off function and be aware that any meter-run temperature differences will cause thermal convection currents of gas to circulate inside the meter, which the USM may measure as a very low flowrate.

13 FIELD VERIFICATION TESTS

The manufacturer shall provide a written field verification test procedure to the operator that should allow the USM to be functionally tested to ensure that the meter is operating properly. These procedures may include a combination of a zero-flow verification test, speed-of-sound measurement analysis, individual path measurement analysis, internal inspection, dimensional verification and other mechanical or electrical tests.

The manufacturer should provide an uncertainty analysis to demonstrate that these field performance verification tests are sufficient to validate the meter's specified physical and electrical performance. characteristics. The manufacturer should make reference to the uncertainty method used in this analysis.

Some performance aspects of the USM condition shall be evaluated by comparing the speed of sound reported from the meter with the speed of sound derived from the A.G.A. Report No. 8 — Detailed characterization method. A chromatographic analysis from a sample of gas taken at the time of speed-of-sound measurement is required for valid comparison. An extended analysis shall not be necessary for typical natural gas mixtures.

The decision to perform periodic transfer proving or flow-calibration is left to the parties using the meter.

14 FIELD CALIBRATION

14.1 Type Testing at Work

Type test includes extensive tests in order to verify the compliance to all requirements of the standard.

The design of the USM electronics shall be tested to demonstrate that the USM will continue to meet the performance requirements while operating under the influences and disturbances specified in the current revisions of OIML R6, and OIML D11, OIML is the Organization Internationale de Metrologie Légale, that is, the International Organization of Legal Metrology.

For the climatic conditions the requirements shall be for class 4K3, 'open locations with average climatic conditions, thus, excluding polar and desert environments'. For the mechanical conditions the requirements shall be for class 3/4M5, 'locations with significant or high levels of vibration and shock' for example, transmitted from adjacent compressors. The combination of these two conditions leads to OIML class F for determining the severity level for each test.

Type test includes flow tests for the determination of the L_{Min} of the calibration facility in order to find the upstream piping configuration defining a reference flow-condition. This will be the preferred set up for conducting the flow-calibrations.

14.2 Accuracy

The accuracy limits shall be met within q_{Max}, design and q_{Min}.

The tests shall be conducted under undisturbed flow-conditions with the following flowrates: 120 percent, 100 percent, 70 percent, 40 percent, 25 percent, 10 percent, 5 percent of q_{Max} design.

The duration of one measurement shall be at least 300 s, 3 times 100 s or 400 D/v, whichever is larger.

The repeatability test shall be conducted for at least one flowrate below q_t and at least one flowrate above q_t. For each of these flowrates 10 single measurements shall be taken with the duration of the measurement as given above.

For the reproducibility test the same meter shall be tested under exactly the same installation conditions with a time difference of at least 1.

15 MARKING

The meter shall be marked with at least the following information:

a) Manufacturer's name or trade-mark;

b) serial number;

c) Maximum flowrate, q_{Max} in actual volume units;

d) Maximum allowable operating pressure; and

e) Minimum flowrate, q_{Max} at 1.2 kg/m^3 fluid density.

15.1 BIS Certification Marking

The product may also be marked with the Standard Mark.

15.1.1 The use of the Standard Mark is governed by the provisions of the Bureau *of Indian Standards Act*, 1986 and the Rules and Regulations made thereunder. The details of conditions under which the licence for the use of Standard Mark may be granted to manufacturers or producers may be obtained from the Bureau of Indian Standards.

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Amendments are issued to standards as the need arises on the basis of comments. Standards are also reviewed periodically; a standard along with amendments is reaffirmed when such review indicates that no changes are needed; if the review indicates that changes are needed, it is taken up for revision. Users of Indian Standards should ascertain that they are in possession of the latest amendments or edition by referring to the latest issue of 'BIS Catalogue' and 'Standards: Monthly Additions'.

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IS 15674 : 2006 FLOW MEASUREMENT OF NATURAL GAS BY ULTRASONIC METER

(*Foreword, last para, lines* 5, 6 *and* 7) — Substitute 'American Gas Association' *for* 'American gas authority'.

(*Page* 8, *Fig.* 1) — Substitute 'REPEATABILITY' *for* 'REPATABILITY'.

(PG 26)

Reprography Unit, BIS, New Delhi, India